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Size Distribution of Particles That May Contribute to Soiling of Material Surfaces

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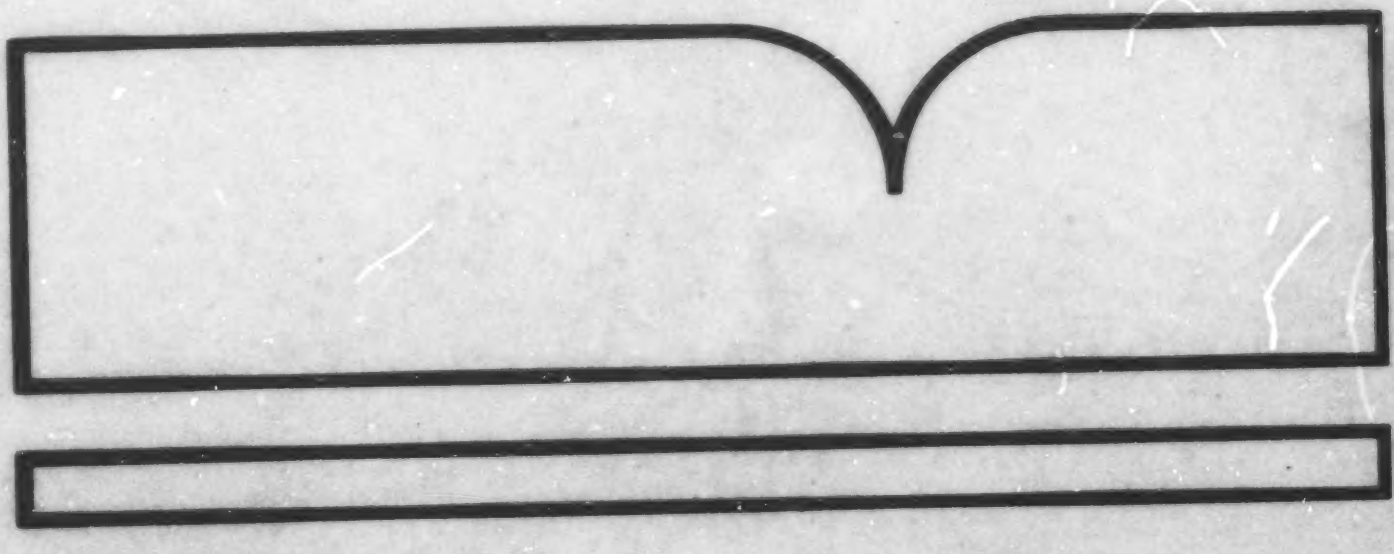

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16. ABSTRACT

The body of information presented in this paper is directed to those individuals concerned with criteria for secondary ambient air quality standards for particles. The distribution of size of particles deposited on glass was determined by light and scanning electron microscopy. Particles larger than 10 μm dominate soiling on glass. More definitive research is needed, especially on rough surfaces.

micrometers

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APCA NOTE-BOOK

Size Distribution of Particles That May Contribute to Soiling of Material Surfaces

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In November 1983, EPA held a workshop entitled Research Strategies to Study the Soiling of Buildings and Materials.[1] One of the main subjects of discussion was what size of particle contributes most to soiling and, related to that, what ambient air measurement technique provides the best proxy for soiling potential. Because of this interest and its implications on future research and possible regulations, the following "quick and dirty" experiment was performed.

Experimental Procedure

Two thin pieces of glass, each having a one side area of approximately 10 mm^2 were taped to glass microscope slides. In February, one of the slides was mounted vertically on a post under a mailbox. The mailbox was approximately two meters from an uncurbed asphalt suburban roadway with a traffic rate of approximately 13,000 vehicles per day. The other was placed on a window sill at an angle of approximately 70° to the horizontal at approximately 20 m from the same road. One month later, the pieces of glass were removed and examined by both light and scanning electron microscopy.

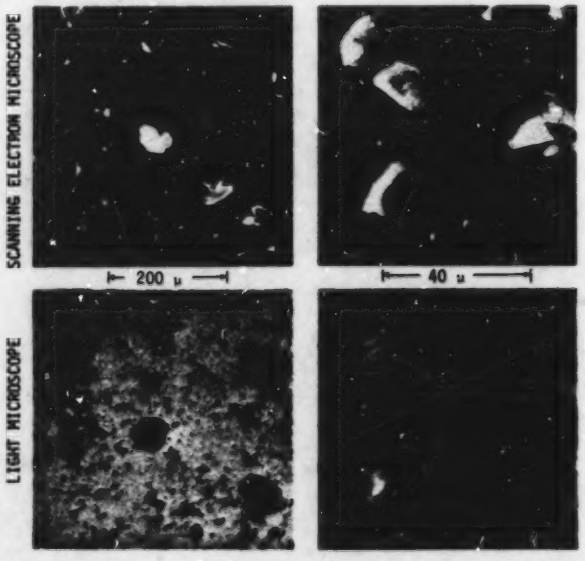

Figure 1. Particles deposited on glass near a busy roadway.

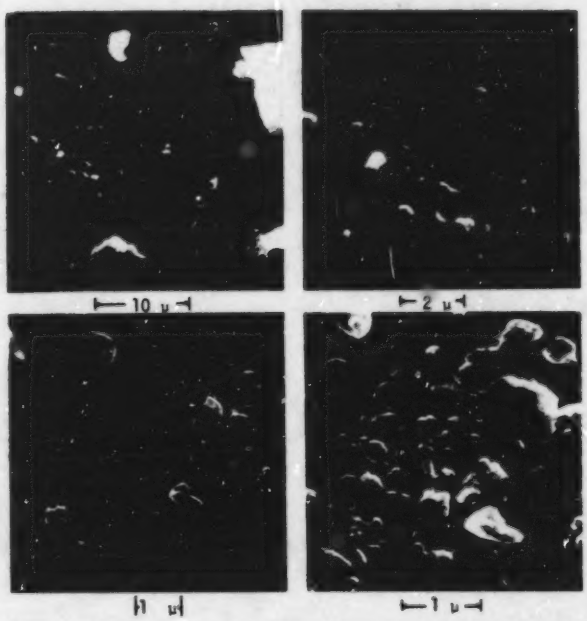

Figure 2. Scanning electron micrographs of small particles on glass near a busy roadway.

Light micrographs were taken at magnifications of 93×, 236×, 370×, and 590×, and scanning electron micrographs were taken at 100×, 600×, 2000×, 5000×, 10,000× and 20,000×. Particle size counts were made on each micrograph. For sizing purposes, nonspherical shapes were assumed to have a diameter equal to the square root of the product of two primary dimensions.

A different technique was used to determine whether the amount deposited on a small piece of glass is representative of the amount accumulated on windows over a long period of time. Clear paint was sprayed on a garage window that was approximately 40 m from the road. The window had not been washed in over 10 years and had been exposed to blowing rain. The dried film was stripped from the glass and examined with a light microscope (particles were embedded in the film and could not be seen with the scanning electron microscope).

Results

Figure 1 is a composite of scanning electron and light micrographs at comparable magnifications for the glass exposed

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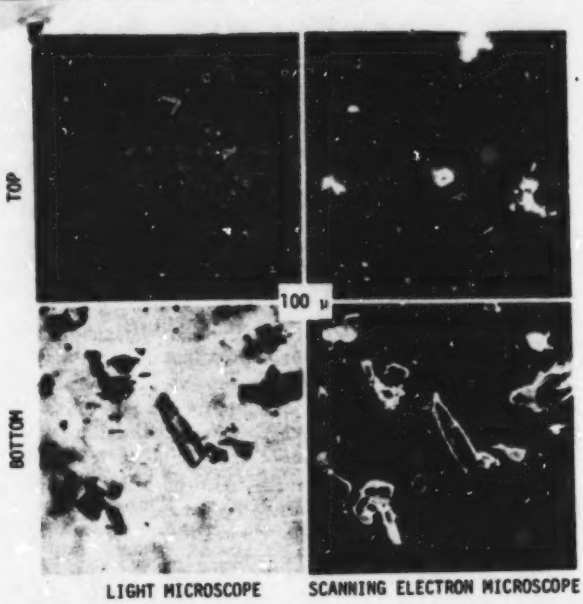

Figure 3. Particles deposited on glass at 70° to the horizontal on a window sill.

near the road. The central spherical particle in the low magnification light micrograph is pollen (deformed when bombarded with electrons). Pollen particles were not counted. The dark irregular shapes in the light micrographs are particles of tire rubber. Most of the other nonspherical particles are earth materials.

Figure 2 shows the distribution of submicron particles deposited on the glass near the road. Distribution was not uniform on the samples.

Figure 3 is a composite of low magnification micrographs of particles deposited on the glass at the window sill. The glass was not protected from rain, and the very large particles tended to wash to the bottom. Because the glass was at an angle of approximately 70°, gravitational settling contributed to the deposition of the larger particles. Although most of the irregular shapes are crystalline earth materials, some are particles of rubber from the road.

Figure 4 shows that the distribution of particles accumulated on a window is similar to that deposited on a small piece of glass. It indicates that particles larger than 10 μm adhere to vertical surfaces and contribute significantly to soiling.

Particle counts in size intervals of one-third the logarithm of decade diameter were made on each micrograph. Counts were adjusted between magnifications by multiplying by factors to give the number of particles per square millimeter of glass surface. These counts were then correlated to the mid-diameters of the intervals by using a fourth degree polynomial regression (Table I).

$$N = \mathrm{Exp}[A_0 + A_1 \ln D + A_2(\ln D)^2 + A_3(\ln D)^3 + A_4(\ln D)^4] \quad (1)$$

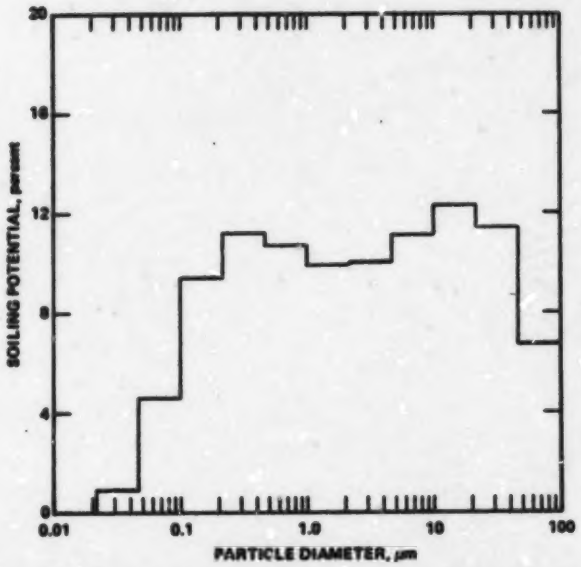

Figure 5. Distribution of soiling potential as a function of particle diameter on glass near roadway.

where N = number of particles per mm² within the interval
D = mid-diameter of the interval in micrometers
A_i = regression coefficients

The regression equation for the two samples were then used with the mid-diameters of each interval to calculate the number of particles, the limits of one standard deviation range, particle cross sectional area per square millimeter of glass surface area, the percent of total coverage, and the percent of total particle volume. The results are given in Table II. Figures 5 and 6 show the bimodal character of the soiling effect.

Figure 4. Particles in a clear paint film applied and stripped from a dirty garage window (partially polarized light).

Table I. Fourth degree polynomial regression results of ln N as a function of ln D.

	Near road		Window sill	
	Coefficient	Standard error	Coefficient	Standard error
A_0	9.7968	0.2193	8.6002	0.2060
A_1	−2.0986	0.1345	−2.1632	0.1326
A_2	0.0413	0.0653	−0.0904	0.0667
A_3	0.0390	0.1193	0.0476	0.0113
A_4	−0.0116	0.0523	−0.0043	0.0038
Standard error of estimate	1.3191		0.9602	

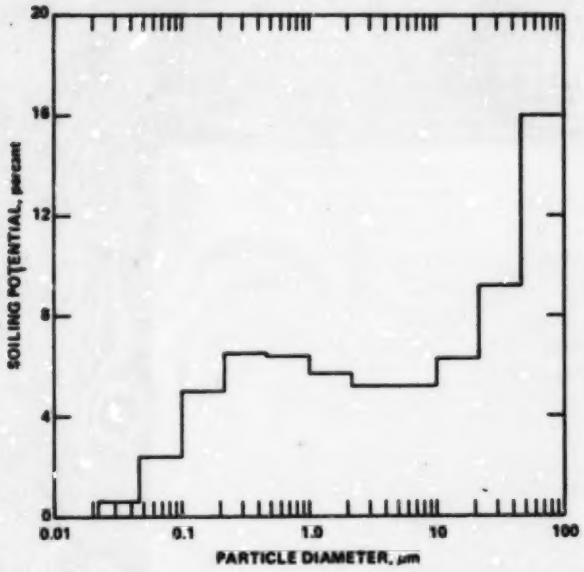

Figure 8. Distribution of soiling potential as a function of particle diameter on glass at window sill.

Discussion

These calculations reveal several facts. Most significant is that a few very large particles deposited by gravitational settling can dominate both particle volume and cross-sectional area measurements. By considering surface coverage as soiling, 99% of the volume and 63% of the soiling on the glass at the window sill was caused by only 39 particles, with a diameter greater than 10 μm. Even on the vertical glass near the road, where gravity did not contribute to deposition, large particles were dominant. Particles with diameters greater than 10 μm account for 90% of the volume and 32% of the soiling. The total soiling was significantly greater on the glass near the road than on the glass on the window sill, 0.138 mm^2/mm^2 compared to 0.070 mm^2/mm^2. This was consistent with the expectation that the ambient concentration of particles is greater near the primary source.

Conclusions

1. Coarse particles dominate soiling of smooth surfaces such as glass.
2. A sampler designed to collect particles with diameters less than 10 μm would be a very poor indicator of soiling on these surfaces.
3. A hi-vol sampler may provide a fair indicator of soiling on vertical surfaces but would be poor for horizontal surfaces, where settling dust is the dominant fraction.
4. More definitive research is needed, especially for rough surfaces for which deposition velocities of submicron particles are expected to be two to three orders of magnitude higher than for smooth surfaces.

Acknowledgment

I greatly appreciate John L. Miller's assistance with the scanning electron microscopy.

Reference

1. F. H. Haynie, J. W. Spence, "Final Report of the EPA Workshop on Research Strategies to Study the Soiling of Buildings and Materials," U.S. EPA, Research Triangle Park, NC, April 1984.

Mr. Haynie is Chief, Special Techniques Group, Atmospheric Sciences Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. This note manuscript was peer reviewed.

Table II. Particle size distribution on glass.

Location	Diameter range (μm)	Number per mm^3			Area		Volume
			S.D. limits				
		Median	Lower	Upper	mm^2/mm^2	%	(%)
Near road	0.010–0.021	3.54×10^5	9.47×10^4	1.32×10^6	0.0001	0.0	0.0
	0.022–0.045	1.59×10^5	4.26×10^4	5.96×10^5	0.0013	0.9	0.0
	0.046–.099	1.75×10^5	4.67×10^4	6.53×10^5	0.0064	4.6	0.0
	0.100–0.214	7.61×10^5	2.03×10^5	2.85×10^6	0.0129	9.4	0.1
	0.215–0.463	1.96×10^5	5.25×10^4	7.34×10^5	0.0154	11.2	0.3
	0.464–0.999	4.04×10^4	1.08×10^4	1.51×10^5	0.0147	10.7	0.5
	1.00–2.14	8.10×10^3	2.17×10^3	3.03×10^4	0.0137	9.9	1.1
	2.15–4.63	1.76×10^3	4.71×10^2	6.59×10^3	0.0138	10.0	2.3
	4.64–9.99	4.20×10^2	1.12×10^2	1.57×10^3	0.0153	11.1	5.5
	10.0–21.4	1.00×10^2	2.68×10	3.75×10^2	0.0170	12.3	13.1
	21.5–46.3	2.00×10	5.35	7.48×10	0.0157	11.4	26.1
	46.4–99.9	2.52	6.73×10^{-1}	9.41	0.0092	6.7	33.0
	100–215	1.37×10^{-1}	3.65×10^{-2}	5.11×10^{-1}	0.0023	1.7	17.9
Window sill	0.010–0.021	2.05×10^5	7.85×10^4	5.35×10^5	0.0000	0.0	0.0
	0.022–0.045	5.04×10^5	1.93×10^5	1.32×10^6	0.0004	0.6	0.0
	0.046–0.099	4.62×10^5	1.77×10^5	1.21×10^6	0.0017	2.4	0.0
	0.100–0.214	2.00×10^5	7.95×10^4	5.43×10^5	0.0035	5.0	0.0
	0.215–0.463	5.81×10^4	2.22×10^4	1.52×10^5	0.0046	6.5	0.0
	0.464–0.999	1.24×10^4	4.74×10^3	3.23×10^4	0.0045	6.4	0.0
	1.00–2.14	2.36×10^3	9.05×10^2	6.18×10^3	0.0040	5.7	0.1
	2.15–4.63	4.61×10^2	1.77×10^2	1.21×10^3	0.0036	5.2	0.3
	4.64–9.99	1.01×10^2	3.86×10^2	2.64×10^2	0.0037	5.2	0.6
	10.0–21.4	2.62×10	1.00×10	6.84×10	0.0041	6.3	1.5
	21.5–46.3	8.22	3.15	2.15×10	0.0065	9.2	4.7
	46.4–99.9	3.07	1.18	8.03	0.0112	16.0	17.7
	100–215	1.30	0.50	3.39	0.0220	31.4	74.9